

This could be revised title of the manuscript: Variability of fruit and seed characters in *Jatropha curcas* L. accessions grown in semi-arid site of Senegal

Original Research Article

Title: Variability of fruit and seed characters and oil content of 35 accessions of *Jatropha curcas*

L. grown in a semi-arid site in Senegal

Abstract

space

Aim: This study has evaluated variations in seed and fruits traits as well as the oil content of 35 accessions of *Jatropha curcas* grown in the same soil, and agroclimatic conditions in Senegal.

Methodology: The study was conducted on 35 accessions of *J. curcas* planted at the research station of Ecole Nationale Supérieure d'Agriculture located in Thies, Senegal. Fruits were collected from 1-4 years old plantations. Then, for each accession, 30 dry fruits were randomly selected and were subjected to measurements of the size parameters (length, diameter) and weight using ~~respectively~~ an electronic caliper and an electronic balance. Fruits were peeled and shells weighed. A sample of 20 seeds per accession was selected with 3 replications for seed traits measurements (length, width and thickness) and seed oil content by Soxhlet method.

Results: The results showed significant differences ($p < .001$) in seed and fruit traits as well as the oil content between accessions. Oil content, weight of kernel / weight of seed coat ratio and 100-seed weight are highly correlated quantitative characters which have also, high heritability broad sense (92.51%, 100% and 87.14% respectively) and genetic advance values (39.32%, 36.44% and 28.77% respectively). Also, this study has highlighted four local accessions (Keur Samba Gueye, Notto 3, Ndary and Soutra) with high oil content ($> 55\%$).

Conclusion:

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There is high genetic variability of *Jatropha curcas* in Senegal in terms of seed, fruit and oil traits. The quantitative characters such as oil content and 100-seed weight might be used for early selection of promising accessions. The local *J. curcas* plant material is interesting enough to perform breeding programs and support national sustainable production of biofuel.

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25 **Key words:** *Jatropha curcas*, seeds, variability, oil content, Senegal, West Africa

1. Introduction

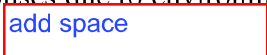
The energy issue is widely discussed in the world, because of the widening gap between decreasing supply and an increasing demand. This imbalance leads to a global crisis that affects the countries' economy. None African oil producers countries like Senegal are more affected by this crisis. For example in 2006, almost 140 billion CFA francs were spent to subsidize the energy sector. Also, Senegal's oil bill rose from 185 billion FCFA in 2000 to 384,000,000,000 FCFA in 2006 and to 623 billion FCFA in 2008, an increase of over 40% in two years. Also, over 46% of export revenue are mobilized to meet this invoice [1]. This energy shortage has created a renewed interest in renewable energy. Senegal, like some African countries embarked on biofuel production by opting for the promotion of *Jatropha* (*Jatropha curcas* L.).

The choice of this plant is justified by the fact that its seeds contain oil of high energy value whose properties are comparable to those of diesel. In addition, this plant is little exigent. It provides various products and benefits that promote an integrated rural development [2].

However, there are many agronomic challenges to overcome for a sustainable development of *Jatropha* biofuel value chain. Among them, the increase in seed yield or in oil content is probably the most emergent for producers. This might involve identifying a more productive plant material and the development of suitable cropping systems.

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Therefore, many studies have been conducted in Asia [3, 4, 5, 6] as well in West Africa [7, 8, 9] on agromorphological, biochemical and genetic characterization of *Jatropha*'s germplasm. These studies have shown a high variability in seed traits and oil content between accessions. This suggests that the accessions analyzed are different ecotypes well adapted to different local conditions. However, this hypothesis cannot be validated if and only if, a genetic basis of

48 variation is established and phenotypic plasticity responses due to environmental differences can
 49 be excluded.  
 50 Unfortunately, this is not the case for the studies carried out in West Africa [7, 8, 9]; these works
 51 have compared different accessions using seeds harvested or 
 52 In this context, the objective of this work is to analyze variability in seeds and fruits traits as well
 53 as oil content of 35 accessions of *J. curcas* collected from different agroclimatic zones of Senegal
 54 ~~but~~ which have been planted on the same site. 

55 2. MATERIAL AND METHODS

56 2.1 Study area


 57 The present study was conducted at the research station of “Ecole Nationale Supérieure
 58 d’Agriculture (ENSA)” located in Thies city, Senegal (latitude 14° 42'52" N; longitude 16°
 59 28'64" O). The climate is tropical semi-arid with an annual average rainfall of about 450 mm [10].
 60 However, the total rainfall of the study year recorded by a weather station is 500.02 mm. The
 61 minimum mean annual ambient temperature is 20° C and a maximum mean annual ambient
 62 temperature of 33° C. [11]. The soils are poorly developed with a sandy loam texture and a pH of
 63 5.0. Their level of fertility is poor with organic carbon and nitrogen, respectively, less than 5%
 64 and 0.3% [12].
 65 The mean annual minimum ambient temperature is 20° C and the mean annual maximum
 66 ambient temperature is 36° C, with a marked seasonal variation [13].

67 2.2 Plant material

space

68 The plant material consists of 35 accessions of *J. curcas* planted in the research station of “Ecole
69 Nationale Supérieure d’Agriculture” (ENSA). Thirty three are from Senegal while 2 others were
70 introduced from Mozambique (Southern Africa) and Tanzania (East Africa).

71 2.3 Methods of the survey

space

72 The fruits were collected between September 9th and December 12th, 2013 from plantations of 1-4
73 years old. For each accession, harvesting was done on 4-6 trees among the most vigorous. Only
74 ripen fruits of yellow or brown color were collected and then dried in the laboratory at ambient
75 temperature (about 25 °C).

76 For each source, 30 fruits were randomly selected. They were pre-dried in an oven at a
77 temperature of 65 °C for 72 hours to obtain a constant weight. Then, each fruit has its length and
78 diameter measured using an electronic caliper, the weight was also determined with an electronic
79 balance (1/1000 g). At the end of these measurements, 30 fruits were peeled and shells were
80 weighed with the same balance as before. To determine seeds traits, a sample of 20 seeds per
81 accession was selected with three (3) replications. These seeds were subjected to measurement of
82 the length (longitudinal axis of the seed with electronic calipers), the width (lateral axis of the
83 seed) and the thickness (radial axis).

84 The weight of each lot of 20 seeds was measured with an electronic balance (1/1000 g). From the
85 weight of 20 seeds, 100-seed weight were calculated :

86 $\text{Weight of 100 seeds (g)} = (\text{Weight of 20 seeds} / 20) \times 100$

87 For each accession, the three lots of 20 seeds that were used to determine seed traits were used
 88 also, to measure the average seed oil content by Soxhlet method [3]. To do this, the kernel was
 89 separated from husks and placed space 5 °C for 48 hours. Then, they were crushed
 90 using a mortar. Thereafter, it was taken 2 g of kernel (sample) for Soxhlet extraction with 3
 91 replications per accession. The oil content of the kernel was determined by the following formula:
 92 % oil = (oil mass / mass of sample) * 100

93 2.4 Data analysis Method

94 Analysis of variance was performed using the software called Statistix to highlight the influence
 95 of the accession factor over the seed and fruit-shape variables as well as the oil content.
 96 Comparison of means was performed using Tukey's test at 5%.
 97 Genetic parameters were estimated to identify the genetic variability between accessions and
 98 determine the effects of the genotype and environment on various studied traits mention Authors with year
 99 and phenotypic variance components, coefficients of variation, heritability in the broad sense and
 100 genetic gain were calculated by adjusting the formula suggested by [14] and [15]:

$$101 \sigma^2_g = (\text{genotypic variance}) = (\text{MSG} - \text{MSE}) / r$$

102 MSG = inter accession variance;

$$103 \sigma^2_E = \text{MSE} = \text{environmental variance};$$

104 r = number of replications;

$$105 \sigma^2_p = (\text{phenotypic variance}) = (\sigma^2_g + \sigma^2_E)$$

$$106 \text{PCV (phenotypic coefficient of variation)} = (\sqrt{\sigma^2_p} / X) * 100$$

107 X = mean of traits;

108 GCV (genotypic coefficient of variation) = $(\sqrt{\sigma^2_g}) / X * 100$

109 h^2B = (broad sense heritability) = σ^2_E / σ^2_p

110 = GA (genetic gain) = $K * (\sqrt{\sigma^2_p}) / X * 100 * H2B$

111 ~~K = constant = 2.06~~

cite reference

112 The XLSTAT 2010 software was used for testing significance of Pearson correlation coefficients

113 and thus assesses the relationships between the different variables studied

114 A hierarchical clustering based on the calculation of the Euclidean distance between the

115 accessions has been performed using the software PAST. It generated a dendrogram that grouped

116 the accessions according to the similarity of their behavior on the studied variables.

117 3. RESULTS

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space

118 3.1 Variability in fruits, seeds and oil content traits

119 The results of the analysis of variance (Table 1) show that the accession-factor has a significant
120 influence on all morphological parameters of fruits and seeds and the oil content ($p < .0001$).

121 The coefficients of variation are highest for fruits traits with values of 23.92% for weight, 8.98%
122 for diameter and 7.69% for length. For seeds, the highest coefficients of variation were obtained
123 with Kernel weight/Seed coat weight (K/SC) ratio (7.60%), 100-seed weight (5.78%) and oil
124 content (5.65%).

125 The average values of seed traits are: 18.25 mm for length, 11.04 mm for width, 8.70 mm for
126 thickness, 60.25 g for 100-seed weight, 44.68% for oil content and 1.26 for K/SC ratio. For fruits,

σ^2_g / σ^2_p

$K * \sigma_p * h^2$

K=selection intensity at 5%
population selected= 2.06
 σ_p = phenotypic standard deviation
 h^2 = broad sense heritability

the average values of the measured parameters are 25.68 mm for length, 20.19 mm for diameter and 2.34 g for weight.

For the different studied parameters, the accessions that obtained the highest values are:

- 17 (19.16 mm), 19 (19.11 mm) and 7 (19.03 mm) for seed length;
- 9 (11.41 mm), 20 (11.35 mm) and 30 (11.32 mm) for seed width;
- 7 (9.22 mm), 13 (9.09 mm) and 17 (9.06 mm) for seed thickness;
- 24 (72.65 g), 31 (72.65 g) and 13 (71.00 g) for 100-seed weight;
- 24 (57.16%), 31 (56.50%) and 13 (55.33%) for oil content;
- 24 (1.65), 31 (1.63) and 26 (1.58) for K/SC ratio;
- 19 (27.29 mm), 6 (27.16 mm) and 8 (26.99 mm) for fruit length;
- 27 (21, 64 mm), 6 (21.54 mm) and 17 (21.45 mm) for fruit diameter;
- 31 (2.91 g), 35 (2.82 g) and 27 (2.77 g) for fruit weight.

Table 1. Seed, fruit and oil content traits variability in *Jatropha curcas*

Accession No.	Locality	Seed						Fruit		
		Length (mm)	Width (mm)	Thickness (mm)	weight (g)	coat ratio	Oil content (%)	Length (mm)	Diameter (mm)	Fruit weight (g)
1	Karang	18,37	11,02	8,78	64,65	1,40	47,00	25,38	20,36	2,45
2	Darou mousty	17,44	11,31	8,30	52,00	1,05	36,66	25,10	19,23	2,10
3	Dianamalary	18,74	11,04	8,86	62,30	1,19	46,33	26,55	21,10	2,48
4	Diassime Mandina	18,06	10,65	8,62	56,65	1,15	42,33	25,96	20,33	2,20
5	Diouroup	18,88	11,08	8,96	67,30	1,25	53,00	26,51	20,56	2,44
6	Fimela	18,65	11,09	8,74	65,65	1,32	52,66	27,16	21,54	2,67
7	Fois 1	19,03	11,24	9,22	67,00	1,23	51,83	25,35	20,18	2,16
8	Gandiaye	18,17	10,99	8,65	64,65	1,29	48,83	26,99	20,59	2,7

9	Ngoutle	17,25	11,41	8,23	43,75	0,77	30,16	24,41	18,61	1,89
10	Gourel Bowe	17,39	10,81	8,39	48,00	0,92	30,33	24,66	18,62	1,90
11	Kagnobon	16,93	10,32	7,84	31,30	0,74	23,00	21,48	17,14	1,30
12	Kamonghone	16,89	10,87	8,16	56,30	1,37	43,00	23,23	19,07	1,94
13	Keur Samba Gueye	18,93	11,21	9,09	71,00	1,46	55,33	26,96	21,22	2,49
14	Koumbal	18,31	10,75	8,11	48,65	1,06	32,16	25,63	20,43	2,19
15	Linguere	18,66	10,93	8,73	58,00	1,11	42,66	26,34	20,35	2,26
16	Lompoul	17,17	11,28	8,25	52,30	1,23	35,33	24,61	19,24	2,15
17	Madiop Boye	19,16	11,30	9,06	68,00	1,41	54,00	26,71	21,45	2,70
18	Maleme Hoddar	18,43	10,96	8,82	67,00	1,48	50,16	26,08	19,83	2,32
19	Maleme Niani	19,11	11,26	8,73	57,65	1,06	42,33	27,29	20,20	2,30
20	Medina Sabakh	17,76	11,35	8,88	63,30	1,32	46,33	25,23	19,07	2,23
21	Mozambique	18,13	10,84	8,75	61,65	1,36	44,00	25,64	20,56	2,28
22	Mpack	18,07	10,53	8,52	62,30	1,40	44,50	26,39	20,37	2,70
23	Ndande	18,09	11,00	8,47	56,00	1,11	40,83	25,96	20,41	2,35
24	Ndary	19,00	11,15	8,89	72,65	1,65	57,16	26,04	20,54	2,69
25	Nguekokh	17,88	10,67	8,64	56,00	1,23	39,83	25,13	20,08	2,16
26	Notto 3	18,78	11,04	8,71	70,65	1,58	55,16	25,44	20,69	2,70
27	Ouassadou	18,63	11,10	8,92	69,30	1,43	54,50	26,71	21,00	2,77
28	Porokhane	18,11	11,28	9,01	62,00	1,20	44,66	25,02	18,86	2,06
29	Sangalkham	18,32	11,09	8,53	54,65	1,13	36,33	25,60	20,13	2,24
30	Sare Diatta Folere	18,30	11,32	8,67	48,65	0,87	30,83	26,69	20,82	2,03
31	Soutra	18,89	11,22	8,85	72,65	1,63	56,50	26,48	21,27	2,91
32	Tanzanie	18,68	11,31	8,74	68,70	1,53	54,16	25,97	20,66	2,61
33	Tapha Kane	17,69	10,84	8,47	53,00	1,35	36,50	22,81	19,66	1,87
34	Touba Peykoug	18,57	11,03	8,96	68,65	1,47	54,00	26,62	20,69	2,65
35	Velingara	18,30	11,06	8,70	66,30	1,36	51,33	26,59	20,98	2,82
Mean		18,25	11,04	8,66	60,25	1,26	44,68	25,68	20,19	2,34
Minimum		16,89	10,32	8,30	31,30	1,23	23,00	21,48	17,14	1,30
Maximum		19,16	11,41	9,22	72,65	1,65	57,16	27,29	21,64	2,91
Coefficient of variation (%)		1,19	1,17	1,43	5,78	7,60	5,65	7,69	8,98	23,92
F		24,80	11,30	18,10	21,10	16,50	38,10	12,20	8,57	11,20

provide MS values for all traits instead of F

mention LSD values
for all traits at 1%
instead of mentioning
only P

~~P~~

~~0.0001~~

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space

140 3.2.2 Estimation of genetic variables for 9 morphological traits of *Jatropha curcas*.

141 Table 2 shows the values of genetic parameters for different agro-morphological characteristics
142 of the seeds and fruits of *J. curcas*. Its analysis reveals that the oil content has the highest
143 phenotypic and genotypic variances with 84.89% and 78.63% respectively. This character is
144 followed by the fruit length that has respective values of 8.34% and 9.46%. The third character
145 that has the highest variance is the 100 seeds -weight with 3.73% of the phenotypic variance and
146 3.25% for the genotypic variance.

147 Regarding the coefficient of genotypic variation, it appears that the characters that have the
148 highest values are in descending order fruit weight (24.40%), oil content (19.84%), K/SC ratio
149 (17.74%) and 100-seed weight (14.96%). These characteristics also have higher coefficients of
150 phenotypic variation and in the same order than previously.

has

151 The broad sense heritability is high for all of the studied characters except the fruit diameter for
152 which the average value is (43.21%). However, the values are highest in K/SC ratio (100%), oil
153 content (92.51%), seed-length (90.40%), seed-thickness (89.65%) and 100-seed weight
154 (87.14%).

(36.44%)

155 The oil content has the largest genetic advance (39.32%). It is followed by the K/SC ratio with
156 ~~36.44%~~, fruit weight (35.85%) and 100-seed weight with 28.77%.

space

No need to give Variance values, (CV, H and GA are sufficient). since CV is indicator of variability

Estimates

157 Table 2. ~~Estimation~~ of genetic variables for seed, fruit and oil traits in *Jatropha curcas* write point instead of , (3.36) for all values in table

Traits	Variance		Coefficient of variation (%)		Heritability broad sense (%)	Genetic advance (%)
	Genotypic	Phenotypic	Genotypic	Phenotypic		
Length (~~mm~~)	0,37	0,41	3,36	3,53	90,40	6,58
Width (~~mm~~)	0,06	0,07	2,21	2,39	85,71	4,23
Thickness (~~mm~~)	0,08	0,09	3,39	3,59	89,65	6,62
100-seed weight (~~g~~)	3,25	3,73	14,96	16,03	87,14	28,77
Fruit weight (~~g~~)	0,32	0,63	24,40	34,08	51,25	35,87
Fruit diameter (~~mm~~)	2,48	5,75	7,80	11,87	43,21	4,50
Fruit length (~~mm~~)	4,46	8,34	8,22	11,24	53,52	12,39
Oil content (~~%~~)	78,63	84,99	19,84	20,63	92,51	39,32
K/SC*	0,05	0,05	17,74	17,74	100,00	36,44

158 *K/SC = kernel weight / seed coat weight

159 3.3. Analysis of correlation coefficients among 9 morphological traits

space

160 Table 3 shows that oil content is significantly correlated to all the studied parameters. However,
 161 the correlation is greater for 100-seed weight ($r = 0.98$) followed by K/SC ratio ($r = 0.87$), then
 162 fruit weight ($r = 0.85$) and finally seed thickness ($r = 0.80$).
 163 The 100-seed weight was also significantly correlated with all measured parameters. The highest
 164 values are obtained with oil content, K/SC ratio ($r = 0.89$) and fruit weight ($r = 0.87$).
 165 The K/SC ratio has a significant correlation with all other parameters except the width.

166 All parameters are significantly correlated to the length of the seed; however, the correlation is
167 stronger with the fruit diameter ($r = 0.81$) and seeds -thickness ($r = 0.80$).

168 The width is less correlated with other parameters with non-significant values for, comma
169 with K/SCratio, fruit diameter and fruit weight.

170 The thickness is significantly correlated with all other traits fruit and seed traits but with a
171 highest correlation with oil content ($r = 0.80$).

172 As the thickness, fruit length is significantly related to any other parameter; however, this
173 parameter is more correlated with fruit diameter ($r = 0.83$).

174 With the exception of the seed length, the fruit diameter is significantly correlated to all the
175 studied parameters. . full stop

176 Finally, the fruit weight is significantly correlated to the set of measured parameters, However,
177 there is a better link with the fruit diameter ($r = 0.84$).

178 Table 3. Correlation coefficients among 9 morphological traits of *Jatropha curcas*

Variables	Length (mm)	Width (mm)	Thickness (mm)	100- seed weight (g)	K/SC ratio	Oil content (%)	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)
Length (mm)									
Width (mm)	0,338*								
Thickness (mm)	0,803*	0,462*							
100-seed weight (g)	0,748*	0,375*	0,834*						
K/SC**	0,508*	0,155	0,571*	0,886*					
Oil content (%)	0,739*	0,340*	0,800*	0,979*	0,869*				
Fruit length (mm)	0,777*	0,385*	0,656*	0,660*	0,360*	0,614*			
Fruit diameter (mm)	0,807*	0,250	0,630*	0,731*	0,578*	0,702*	0,834*		
Fruit weight (g)	0,712*	0,296	0,614*	0,867*	0,755*	0,846*	0,798*	0,844*	

179 **K/SC = kernel weight/seed coat weight, *Correlation is significant at the 0.05 level.

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3.4 Regression equations for estimating oil content

space

Regression models for estimating oil content are presented in table 4. The statistical analysis of parameters such as the coefficient of determination (R^2) and the probability (p) reveals that three equations are significant and can be used to estimate oil content. However, equation 1 appears to be the best; it allows a very good estimate of the oil content.

space

Table 4. Equations for oil content estimation in *Jatropha curcas*

N°	Equations	R^2	P
1	OC (%) = $0.95 \times (P100) - 12.69$	0.96	< 0.0001
2	OC (%) = $34.67 \times (K/SC) + 0.97$	0.75	< 0.0001
3	OC (%) = $19.94 \times (FW) - 2.44$	0.58	< 0.0001

OC: oil content (%), P100: 100-seed weight (g), FW: fruit weight (g), K/SC: kernel weight / seed coat weight ratio

space

3.5 Cluster analysis

cluster

An hierarchical analysis was realized using data of the nine morphological studied traits of *Jatropha curcas*. The dendrogram obtained revealed five clusters (Figure 1). Cluster 1 (red) includes the maximum accession (12). Clusters 3 (purple) and 4 (green) each have 8 sources. Clusters 2 (blue) and 5 (yellow) ~~respectively~~ 6 and 1 accessions.

consist of

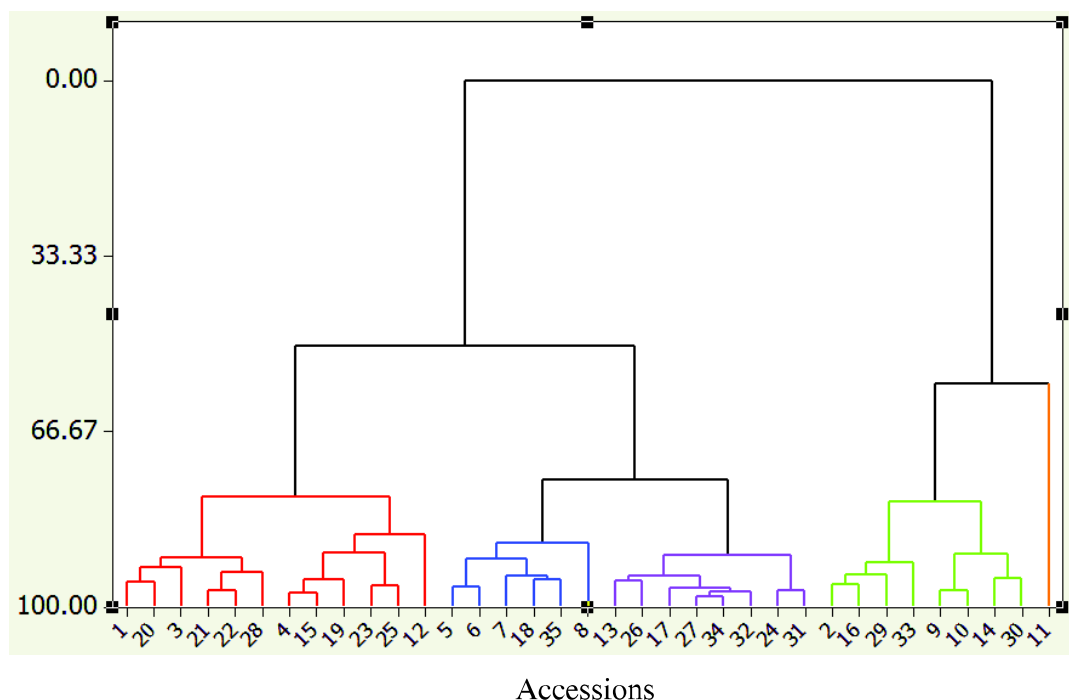


Fig. 1. The dendrogram of 9 morphological traits derived from 35 *Jatropha curcas* accessions constructed using hierarchical analysis method

The distribution of accessions according to the different groups is indicated in

- ~~1, 20, 3, 21, 22, 28, 4, 15, 19, 23, 25 and 12 are the cluster I,~~
- ~~5, 6, 7, 18, 35 and 8 are in the second cluster,~~
- ~~13, 26, 17, 27, 34, 32, 24 and 31 are the third cluster,~~
- ~~2, 16, 29, 33, 9, 10, 14 and 30 are the cluster IV.~~
- ~~11 is the only one of the cluster V.~~

Cluster 3 has the highest values for fruit and seed traits except for fruit length (Table 5). For this group, the average values of seed length, 100-seed weight, oil content and fruit diameter are respectively 18.83 mm, 70.20 g, 55.10% and 20.94 mm. The lowest values of these parameters were observed in cluster 5.

no need to repeat in text as information in line no.199 to 204 is already in table 5

space

space

space

respectively

space

208 Considering only the oil content, it appears that the highest values are observed in clusters II and

209 III.

space

write point (10.95)
instead of comma for
mean values in table

210 Table 5. Cluster mean value for fruit, seed and oil traits in *Jatropha curcas* accessions

Cluster	No of accessions	Accessions	Seed length (mm)	Seed width (mm)	Seed thickness (mm)	100 seed weight (g)	K/SC	Oil content (%)	Fruit length (mm)	Fruit diameter (mm)	Fruit weight (g)
I	12	1, 20, 3, 21, 22, 28, 4, 15, 19, 23, 25, 12	18,15	10,95	8,67	59,73	1,24	43,65	25,67	20,06	2,28
II	6	13, 26, 17, 27, 34, 32, 24, 31	18,57	11,07	8,84	66,31	1,32	51,3	26,44	20,61	2,51
III	8	31, 24, 26, 32, 34, 27, 17, 13	18,83	11,17	8,9	70,2	1,52	55,1	26,36	20,94	2,69
IV	8	2, 16, 29, 33, 9, 10, 14, 30	17,73	11,1	8,36	50,12	1,04	33,53	24,93	19,59	2,04
V	1	11	16,93	10,32	7,84	31,3	0,74	23	21,48	17,14	1,3

211 K/SC = kernel weight / seed coat weight

212 4. Discussion

, comma

and seed

213 This survey was conducted to quantify the variation in morphological characters of seeds and

214 fruits but also the oil content of *J. curcas*, which can be attributed to genetic and environmental

215 factors. For this, an experimental approach was adopted; it is based on the analysis of different

216 characters on accessions from various geographical origins but which were transplanted in the

217 same site where they were subject to the same technical itinerary from sowing to harvesting and

reference, mention
author

218 seed storage. The establishment of the accessions in the common experimental field was made
219 from cuttings therefore perfectly genetically identical material to mother-plant. This is
220 considered by [16] as appropriate to reduce environmental impacts and estimate how much
221 variability due to genotype in *J. curcas*.

traits (length, width,
thickness, 100 seed weight,
K/SC ratio, oil content)

traits (length,
diameter, weight)

222 The study of morphological characters of seeds from natural populations or low anthropic of a
223 species, is an important step for the study of genetic variability [3]. This work has revealed that
~~224 there are significant differences between the 35 studied accessions for the seed length, width and~~
~~225 thickness, 100-seed weight, K/SC ratio, fruit length, diameter and weight and oil content.~~

226 Previous studies have also reported a high variability of morphological traits [8, 9] and seed oil
227 content [8] of *J. curcas* in Senegal. Similar results were obtained from other accessions collected
228 in Africa including Nigeria [7] and Mozambique [16], but also in Asia [17, 3, 4, 6]. They can be
229 attributed to the fact that *J. curcas* ~~grows~~ in a wide range of rainfall, temperatures, and soils
230 [3].

grows

231 The broad sense heritability is an important parameter in the selection of trees since it provides
232 an indication of the relative importance of heredity and environment in the expression of many
233 characters. High values of this parameter indicate that the environment has little influence on the
234 studied traits. However, the use of broad sense heritability requires coupling it with other genetic
235 parameters (variances and coefficients of genotypic and phenotypic variation); such an approach
236 allows selecting characters that are strongly under genetic control and at the same time have a
237 high genetic variability. Our results show that except for fruit diameter, all studied characters
238 have high broad sense heritability values (> 45%); therefore we can consider that these
239 characters are highly heritable. However, oil content, 100-seed weight, K/SC ratio and fruit
240 weight appear to be the most interesting for breeding programs. These four characters have the

241 highest values of heritability in broad sense (51.25 to 100%), genotypic variance (0.32 to 78.63)
 242 and coefficient of variation (14.96 to 24.4%). They also have the highest values of genetic
 243 advance (28.77 to 39.32%). Genetic advance is a parameter that provides information on the
 244 importance of genetic progress resulting from the selection of the best individuals.

245 Oil content, 100-seed weight, K/SC ratio and fruit weight are strongly correlated and this
 246 suggests that there are opportunities to select these characters together. The test of different
 247 linear regressions between these parameters allowed developing equations for a reliable estimate
 248 of the oil content by weight of 100 seeds ($R^2 = 0.96$). The estimation of oil content from the ~~of~~
 249 100-seed weight avoids money expenses and delays associated with oil analysis in laboratory
 250 when producers are interested in estimating the oil content of their plantations after harvesting.

251 The hierarchical analysis performed to classify accessions based on nine (09) studied traits
 252 revealed five ~~(5)~~ clusters, including cluster III which contains eight (08) accessions is the most
 253 interesting for breeding programs; it has the highest values for all characters. If one refers to
 254 ~~[18]~~, we can see that 50% of the accessions of this cluster have high oil content ($> 55\%$); these
 255 accessions are 26 (55.16%), 13 (55.33%), 31 (56.15%) and 24 (57.16%). The hierarchical
 256 analysis also showed that the maximum distance between groups was observed between groups
 257 II and IV. According to ~~[3]~~, this shows a great diversity among the trees of these two groups
 258 whose crossing would provide new hybrids. Consequently, trees belonging to these groups
 259 should be chosen as parents in *J. curcas* breeding programs in Senegal.

260 Finally, this study showed that the geographic diversity of accessions does not necessarily reflect
 261 their genetic diversity. Indeed, the groups shown by the hierarchical classification are each of
 262 them made up with accessions from three main eco-geographical areas of the country. Our

263 observations are consistent with the results of many studies conducted in Senegal [8, 9] and Asia
264 [3, 6].

265 5. Conclusion

266 This study has shown that there is a high variability of seeds and fruits traits as well oil content
267 in *J. curcas* in Senegal. Based on the calculated genetic parameters, all traits examined, with the
268 exception of fruit diameter, can be considered as heritable character. However, the oil content,
269 K/SC ratio, the 100-seed weight and fruit weight are the most interesting characters for breeding
270 programs. They have the highest values and genetic parameters are strongly correlated.

271 The hierarchical analysis revealed a cluster of eight (08) promising accessions for biofuel
272 production among them, 7 are local while the eighth is from Tanzania. They have high levels of
273 oil comparable (> 55%) to the best accessions found in Asia. These results show that the local *J.*
274 *curcas* plant material is interesting enough to perform breeding programs and support domestic
275 production of biofuel. space

276 This study showed also, that the geographic diversity of accessions does not necessarily reflect
277 their genetic diversity space space

278 Finally, this study has developed a simple linear regression for a reliable estimation of the oil
279 content and 100-seed weight; this equation could reduce the money expenses of determining the
280 oil content in the laboratory and easily estimate the oil production ~~plantations of *J. curcas*~~

plantations.
potential of

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